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Human Kinetics
BRIEF REVIEW

The Effects of Plyometric Training on Change-of-Direction Ability: A Meta-Analysis

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Purpose: To show a clear picture about the possible variables of enhancements of change-of-direction (COD) ability using longitudinal plyometric-training (PT) studies and determine specific factors that influence the training effects. ***Methods:*** A computerized search was performed, and 24 articles with a total of 46 effect sizes (ESs) in an experimental group and 25 ESs in a control group were reviewed to analyze the role of various factors on the impact of PT on COD performance. ***Results:*** The results showed that participants with good fitness levels obtained greater improvements in COD performance ($P < .05$), and basketball players gained more benefits of PT than other athletes. Also, men obtained COD results similar to those of women after PT. In relation to the variables of PT design, it appears that 7 wk (with 2 sessions/wk) using moderate intensity and 100 jumps per training session with a 72-h rest interval tends to improve COD ability. Performing PT with a combination of different types of plyometric exercises such as drop jumps + vertical jumps + standing long jumps is better than 1 form of exercise. ***Conclusion:*** It is apparent that PT can be effective at improving COD ability. The loading parameters are essential for exercise professionals, coaches, and strength and conditioning professionals with regard to the most appropriate dose-response trends to optimize plyometric-induced COD-ability gains.

Keywords: effect size, lower limb, quickness, stretch-shortening cycle

Agility has been defined as a rapid whole-body movement with change of velocity or direction in response to a stimulus.[1] A comprehensive definition of agility recognizes the physical demands (strength and conditioning), cognitive processes (motor learning), and technical skills (biomechanics) involved in agility performance.[1] Change-of-direction (COD) ability refers to a movement where no immediate reaction to a stimulus is required, so the direction change is preplanned[1,2] and is affected by strength, power, and speed.[1,2] This ability is required in a range of sports such as running between bases in softball or baseball, running between wickets in cricket, and in some plays in American football.[3–8] While agility movements involve responding to a stimulus,[1] COD ability may influence agility performance in various sports such as invasion sports. However, this article will focus on the effects of plyometric training (PT) on COD ability. Previous studies examined the influence of different types of training methods including resistance training, PT, and combined PT and resistance training on the development of COD performance.[1,3,4,7–11] A popular training method for improving COD performance is PT, because it has been established as an effective, time-efficient, and easy way to implement training.[3,5,11]

PT refers to exercises that are designed to enhance muscle, mainly through the use of jump training.[12,13] Plyometric exercises constitute a natural part of most sport movements because they involve jumping, hopping, and skipping.[12,13] The identifying feature of plyometric exercise is a lengthening (eccentric contraction) of the muscle–tendon unit followed directly by a shortening or concentric contraction, otherwise termed a stretch-shortening cycle (SSC).[13] The SSC is integral to plyometric exercise because it enhances the ability of the muscle–tendon unit to produce maximal force in the shortest amount of time.[13,14]

The effects of PT may differ depending on various subject characteristics (ie, training level, gender, age, sport activity, or familiarity with PT) and training variables (ie, surface of PT, rest interval between sets and training sessions, type of PT, and the principle of specificity).[3–7,11,15,16–31] For example, jumping exercises that were nonspecific to COD (ie, vertical-type jump exercise) did not have any effect on COD performance.[7] When exercises were specific (eg, lateral bounds, side hops, angles hops) to COD, the training program had a positive effect on COD performance.[3,4,6,7,11,15,32]

In the literature, a number of studies investigated the influence of PT on COD ability and found improvements[3–7,11,15,16–31] and no changes[12,33] after a period of training. Although studies exhibited improvements in COD ability (ranging from 0.3 to 1.89 s using depth jump [DJ], countermovement jump [CMJ], and mixed jump), the rate and magnitude of changes depend on several factors. The possible mechanisms of COD gains could be developments of force and high power output, as well as the ability to efficiently use the SSC in ballistic movements.[3–5,22] In contrast, other authors failed to report significant positive effects of PT on COD gains.[33] Furthermore, the characteristics of a training program that achieves better gains are not clear.[15,19–32]

Longitudinal PT studies combined some of these training variables and found conflicting results on the magnitude of improvements in COD performance. In addition, other factors that influence the effectiveness of a PT program may be duration and PT volume. In this case, studies have used numerous combinations of duration, intensity, and volume characteristics. Therefore, the optimal combination of these factors for maximum

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enhancement in COD performance is not clear. In addition to PT design, other variables that affect the rate of COD gain among studies may be different tests applied in PT studies. Some of the studies used T test,[3,4,11,15] the Illinois Agility Test (IAT),[3,4,15,19] and shuttle run[3,20,24,33] and found different results. On the other hand, there are many tests to identify changes in COD ability after PT, but the suitable test for measuring COD ability after PT has not yet been elucidated.

One of the important factors that affect the results of studies could be small sample size used in training interventions. Unfortunately, when studies are performed with small sample sizes that limit statistical power, they increase the likelihood of the researcher failing to express differences between treatments when in fact such differences exist. Typically, in PT studies the researchers used 8 to 12 subjects in each training group,[32,33] and this sample size is small to exhibit the effect of PT on COD ability. Evidently, most PT studies had insufficient statistical power to detect not only small to moderate but also large treatment effects. One method that allows us to overcome the problem of small sample size and low statistical power is the meta-analysis.

The meta-analysis is now widely accepted as the gold standard for literature review and offers many powerful tools for clarifying research results on a particular topic. The steps of the meta-analytic review increase the scope, objectivity, and quantification of the overall body of literature on a particular topic.[34,35] Steps for thoroughly searching the literature, coding study characteristics, extracting and standardizing data from individual studies, and statistically evaluating treatment effects make the meta-analysis a useful tool when attempting to draw conclusions about the research examining PT for COD improvements. This systematic review especially focuses on research on the effects of PT on COD performance in healthy individuals. Although there are many studies available, the beneficial effect of PT is not clear and has not yet been elucidated. Does PT increase COD performance? If so, what type of PT is best suited for increased COD performance? What manipulation of the acute program variables (choice of exercise, volume, and intensity) is best? Therefore, the purpose of this systematic review with meta-analysis was to examine the influence of various factors on the effectiveness of PT on COD performance and to establish the relative influence of various subject characteristics and training variables on COD improvement.

Methods

To evaluate the effectiveness of PT for increasing COD ability, a meta-analytic review was conducted. Literature searches were conducted electronically to find investigations that examined the effects of PT on COD ability. The research assessed ADONIS, ERIC, SPORTDiscus, EBSCOhost, Google Scholar, Medline, and PubMed electronic databases between June and July 2014 and updated in September 2015. Moreover, manual searches were performed in sport-science-relevant journals. The references of identified articles were examined to identify additional studies that were eligible for the review. The search included all studies published in English and studies in any language for which the abstract was available in English. Key words used were *agility, agility training, agility performance, agility times, change of direction, plyometric training, plyometrics, neuromuscular training, explosive training, power training, jump training, stretch-shortening cycle,* and *quickness*. No age or gender restrictions were imposed during the search stage.

Methodology

For the selection of studies to further review, we performed 3 steps: reading the titles of the articles, reading the abstracts, and reading the whole articles. In this review only human studies and full primary research papers (ie, not a conference abstract, letter to editor, thesis, or review) were eligible for inclusion. In addition, only PT using lower-limb exercises was used, and upper-body PT programs were excluded.

Studies were included if they met the following criteria based on the recommendation of Campbell and Stanley[36]: randomized control studies; high-validity and -reliability instruments; published in a high-quality peer-reviewed journal; athletes or physically active, healthy participants; the PT program was described; and COD ability was measured before and after training. After the search process, 24 articles were included in the analysis[3–7,11,15,16–31] (Table 1 and Figure 1).

Each article was read and coded by 2 investigators for the following variables:

- Descriptive information (age, body mass, height, and group size), type of population (team and individual), practice of plyometrics (familiarized and not familiarized), fitness level ("good" athletes from international or national level, "normal" athletes from regional level, and "regular" athletes with no experience in competitions), gender (male, female, and both), and sport activity (physically active, soccer, rugby, basketball, water polo, and none)
- Program exercises: type of exercise (aquatic PT, land PT, mat PT, grass PT, sand PT, vertical PT, horizontal PT, bilateral PT, unilateral PT, progressive PT, and not progressive PT), intensity of exercise (low, low to moderate, moderate, moderate to high, and high), type of plyometric exercise (DJ, CMJ, DJ-vertical jump-standing long jump [SLJ], hurdle jump, and mixed model [combination of different plyometric exercises]), rest between sets (30, 60, 90, 120, and 180 s), and rest between training sessions (24, 48, and 72 h)
- Program variables: frequency of weekly sessions, program duration, and number of total jumps
- Outcome measurements: the type of COD test used to identify performance gains (eg, T test, IAT, shuttle run, 505, L-run (see Figure 2), 10 × 5-m, and 10-m)

The mean agreement was calculated by intraclass correlation coefficient (ICC). The coding agreement between investigators was determined by dividing the variables coded by the total number of variables. A mean agreement of .90 is accepted as an appropriate level of reliability for such coding procedures.[37] The mean agreement between codings for this study was .96. Any coding differences between investigators were scrutinized and resolved a priori to the analysis.

Gain effect sizes (ESs) were calculated using Hedges and Olkin *g*,[37] using the formula $g = (M_{post} - M_{pre})/SD_{pooled}$, where M_{post} is the mean for the post test, M_{pre} is the mean for the pretest, and SD_{pooled} is the pooled SD of the measurements:

$$SD_{pooled} = \frac{(M_{post} - M_{pre})}{\sqrt{\left[(n_1 - 1)\cdot SD_1^2 + (n_2 - 1)\cdot SD_2^2\right] / (n_1 + n_2 - 2)}}$$

The ES is a standardized value that permits the determination of the magnitude of the differences between the groups or experimental conditions. It has been suggested[38] that ES should be corrected for

Table 1 Summary of Characteristics of All Studies Meeting the Inclusion Criteria

Ref	Year	Gr	Treat	n	G	Age	W	H	Kply	SpoP	ToP	Fit	ES	TG	Freq	Dwk	Int	BH	NTJ	Tply	R	IR	Test
15	2006	E	LPT	14	B	22.3	80.1	175.4	N	NA	I	N	0.7	–0.7	2	6	M	—	730	M	—	48	TT
		E	LPT	14	B	22.3	80.1	175.4	N	NA	I	N	0.31	–0.5	2	6	M	—	730	M	—	48	IAT
		C	—	14	B	24.2	81.2	170	N	NA	I	N	0	0	—	—	—	—	—	—	—	—	TT
		C	—	14	B	24.2	81.2	170	N	NA	I	N	0	0	—	—	—	—	—	—	—	—	IAT
24	2006	E	LPT	8	M	23	68	177	N	PA	I	N	2.1	–0.36	3	8	M	40	5228	M	—	24	SR
33	2007	E	LPT	30	M	—	—	—	Y	PA	I	G	0.1	–0.2	3	10	H	40	1800	HJ+DJ	180	24	SR
		C	—	33	M	—	—	—	Y	PA	I	G	0.02	–0.05	—	—	—	—	—	—	—	—	SR
32	2009	E	LPT	6	M	17.1	68.5	177.2	N	S	T	G	1.3	–0.5	2	6	M	40	—	DJ	—	—	505
		E	LPT	6	M	17.3	68.7	177.9	N	S	T	G	1.5	–0.61	2	6	M	—	—	CMJ	—	—	505
18	2009	E	LPT	14	M	13.3	48.6	159	N	S	T	G	2.8	–0.45	2	8	L	—	—	M	90	—	10-m
		C	—	11	M	13.1	47.8	163	N	S	T	G	–0.5	0.16	—	—	—	—	—	—	—	—	10-m
4	2012	E	MPT	6	M	18	67.5	182.4	Y	B	I	G	1.4	–1.28	3	8	M	—	1188	M	60	48	TT
		E	MPT	6	M	18	67.5	182.4	Y	B	I	G	1.6	–1.15	3	5	M	—	1188	M	60	48	IAT
		E	APT	6	M	18	75.6	180.2	Y	B	I	G	1.3	–1.89	3	8	M	—	1188	M	60	48	TT
		E	APT	6	M	18	75.6	180.2	Y	B	I	G	1.5	–1.09	3	8	M	—	1188	M	60	48	IAT
		C	—	6	M	20.4	60.2	175.3	Y	B	I	G	0.01	–0.08	—	—	—	—	—	—	—	—	TT
		C	—	6	M	20.4	60.2	175.3	Y	B	I	G	0	0	—	—	—	—	—	—	—	—	IAT
19	2013	E	LPT	12	M	21.9	75.9	180.1	Y	S	T	G	0.32	–0.29	2	6	H	30-60-90	410	M	60	48	TT
		E	LPT	12	M	21.9	75.9	180.1	Y	S	T	G	0.97	–0.26	2	6	H	55	410	M	60	48	IAT
		C	—	12	M	22.7	78.6	180.6	Y	S	T	G	–0.25	0.11	—	—	—	—	—	—	—	—	TT
		C	—	12	M	22.7	78.6	180.6	Y	S	T	G	0.22	–0.21	—	—	—	—	—	—	—	—	IAT
6	2013	E	LPT	19	M	18.9	—	—	N	R	T	G	0.61	–0.3	3	4	M	20-40-60	—	M	30	48	TT
		C	—	16	M	18.9	—	—	N	R	T	G	–0.12	0.07	—	—	—	—	—	—	—	—	TT
3	2013	E	LPT	10	M	20.2	78.5	182.1	Y	B	T	G	2.54	–1.22	2	6	M	45	810	DJ,VJ,SLJ	120	72	IAT
		E	LPT	10	M	20.2	78.5	182.1	Y	B	T	G	2.06	–0.64	2	6	M	45	810	DJ,VJ,SLJ	120	72	SR
		C	—	10	M	20.1	79.5	180.1	Y	B	T	G	0.11	–0.07	—	—	—	—	—	—	—	—	IAT
		C	—	10	M	20.1	79.5	180.1	Y	B	T	G	–0.34	0.12	—	—	—	—	—	—	—	—	SR
16	2013	E	MPT	9	M	—	—	—	N	NA	I	N	0.57	–0.3	2	7	L	20-40-60	780	DJ	90	48	IAT
		E	LPT	8	M	—	—	—	N	NA	I	N	0.4	–0.2	2	7	L	20-40-60	780	DJ	90	48	IAT
		E	MPT	7	M	—	—	—	N	NA	I	N	0.33	–0.45	2	7	M	20-40-60	1560	DJ	90	48	IAT
		C	—	5	M	—	—	—	N	NA	I	N	0	0	—	—	—	—	—	—	—	—	IAT
5	2014	E	GPT	38	M	13.2	47.9	154	N	S	I	G	0.26	–0.7	2	7	H	—	—	DJ	90	48	IAT
		C	—	38	M	13.2	47.4	153	N	S	I	G	–0.25	0.4	—	—	—	—	—	—	—	—	IAT
25	2014	E	LPT	13	M	10.4	37	141	N	S	T	R	1.03	–0.4	2	7	H	20-40-60	840	DJ	30	48	L-Run
		E	LPT	14	M	10.4	37.2	141	N	S	T	R	0.87	–0.3	2	7	H	20-40-60	840	DJ	60	48	L-Run
		E	LPT	12	M	10.3	38	142	N	S	T	R	1.04	–0.4	2	7	H	20-40-60	840	DJ	120	48	L-Run
		C	—	14	M	10.1	39	143	N	S	T	R	0.4	–0.1	—	—	—	—	—	—	—	—	L-Run
11	2014	E	LPT	8	F	20.7	53.7	158.7	Y	NA	I	R	1.1	–1.1	2	6	M	—	—	M	60	72	TT

(continued)

Table 1 (continued)

Ref	Year	Gr	Treat	n	G	Age	W	H	Kply	SpoP	ToP	Fit	ES	TG	Freq	Dwk	Int	BH	NTJ	Tply	R	IR	Test
23	2014	E	LPT	7	M	20.5	71.2	176.3	Y	NA	I	N	0.57	–0.92	2	6	M	45	1200	DJ	120	72	TT
		E	SPT	7	M	20.7	72.3	175.5	Y	NA	I	N	0.62	–0.55	2	6	M	45	1200	DJ	120	72	TT
22	2014	E	SPT	10	M	20.7	75.2	180.4	N	NA	I	G	1.5	–1.2	2	6	M	45	1200	DJ	120	72	TT
		E	SPT	10	M	20.7	75.2	180.4	N	NA	I	G	1.3	–1.9	2	6	M	45	1200	DJ	120	72	IAT
		E	SPT	10	M	21.2	70.8	176.7	N	NA	I	G	1.2	–1.5	2	6	M	45	1200	CMJ	120	72	TT
		E	SPT	10	M	21.2	70.8	176.7	N	NA	I	G	1.9	–2.1	2	6	M	45	1200	CMJ	120	72	IAT
		C	—	10	M	19.5	72.5	175.5	N	NA	I	G	0	0	—	—	—	—	—	—	—	—	TT
		C	—	10	M	19.5	72.5	175.5	N	NA	I	G	0	0	—	—	—	—	—	—	—	—	IAT
20	2014	E	LPT	14	M	13.7	45.9	161.5	N	NA	I	N	1.21	–0.56	3	8	L	55	780	M	—	48	SR
		C	—	14	M	13.5	46.6	158.1	N	NA	I	N	–0.28	0.11	—	—	—	—	—	—	—	—	SR
21	2014	E	LPT	12	M	13	51	162.4	N	S	I	G	0.89	–0.71	2	16	L–M	—	—	M	—	72	HAR
		C	—	10	M	12.3	40.8	154.2	N	S	I	G	0.31	–0.18	—	—	—	—	—	—	—	—	HAR
26	2015	E	BPT	12	M	11	43.5	146	N	S	T	R	0.42	–0.3	2	6	M	—	2160	M	—	—	10-m
		E	UPT	16	M	11.6	45	147	N	S	T	R	0.80	–0.5	2	6	M	—	2160	M	—	—	10-m
		E	U+B PT	12	M	11.6	42.2	144	N	S	T	R	0.66	–0.5	2	6	M	—	2160	M	—	—	10-m
		C	—	14	M	11.2	41.8	143	N	D	T	R	–0.06	0.2	—	—	—	—	—	—	—	—	10-m
27	2015	E	PPT	8	M	12.8	53.9	160	N	S	T	N	0.82	–0.85	2	6	M	—	1800	M	60	48	TT
		E	NPPT	8	M	13	53.8	161	N	S	T	N	0.43	–0.7	2	6	M	—	1440	M	60	48	TT
		C	—	8	M	13	53.2	159	N	S	T	N	0.58	–0.74	—	—	—	—	—	—	—	—	TT
17	2015	E	LPT	54	M	14.2	50.3	158	N	S	T	N	0.57	–0.72	2	6	M–H	20	1200	M	120	24	10 × 5
		E	LPT	57	M	14.1	51.8	159	N	S	T	N	0.63	–0.75	2	6	M–H	20	1200	M	120	48	10 × 5
		C	—	55	M	14	52.1	160	N	S	T	N	–0.28	0.5	—	—	—	—	—	—	—	—	10 × 5
29	2015	E	VPT	10	M	11.6	40	144	N	S	I	N	0.43	–0.4	2	6	M	—	1610	M	60	48	10-m
		E	HPT	10	M	11.4	44.6	150	N	S	I	N	0.21	–0.32	2	6	M	—	1610	M	60	48	10-m
		E	V+H PT	10	M	11.2	40.1	141	N	S	I	N	0.7	–0.55	2	6	M	—	1610	M	60	48	10-m
		C	—	10	M	11.4	42.2	146	N	S	I	N	–0.1	0.02	—	—	—	—	—	—	—	—	10-m
30	2015	E	GPT	13	M	15.3	57.1	168	N	S	T	G	1.1	–0.38	2	9	M	—	2240	M	—	72	10-m
		C	—	13	M	14.9	54.4	165.2	N	S	T	G	–0.1	0.02	—	—	—	—	—	—	—	—	10-m
31	2015	E	LPT	10	M	—	—	—	Y	WP	T	G	0.41	–0.30	3	6	M	—	—	M	—	48	TT
28	2016	E	GPT	19	F	22.4	60.7	161	Y	S	T	G	0.85	–0.75	2	6	H	—	—	DJ	60	72	IAT
		E	GPT	21	M	20.4	68.4	171	Y	S	T	G	0.46	–0.4	2	6	H	—	—	DJ	60	72	IAT
		C	—	19	F	20.5	60.2	159	Y	S	T	G	–0.14	0.14	—	—	—	—	—	—	—	—	IAT
		C	—	21	M	20.8	71.5	174	Y	S	T	G	0.05	0.10	—	—	—	—	—	—	—	—	IAT

Abbreviations: Ref, number in reference list; Gr, group; E, experimental; C, control; Treat, treatment; APT, aquatic plyometric training; LPT, land PT; MPT, mat PT; GPT, grass PT; SPT, sand PT; U, unilateral; B, bilateral; PPT, progressive PT; NPPT, no PPT; VPT, vertical PT; HPT, horizontal PT; G, gender; M, male; F, female; B, both; W, weight (kg); H, height (cm); Kply, knows plyometric; N, no; Y, yes; SpoP, sport practiced. PA, physically active; B, basketball; S, soccer; R, rugby; WP, water polo; NA, no athletes; ToP, type of population; I, individual; T, team; Fit, fitness; G, good; N, normal; R, regular; ES, effect size; TG, time gains (s); Freq, frequency, d/wk; Dwk, duration weeks; Int, intensity; L, low; M, moderate; H, high; BH, box height (cm); NTJ, number of total jumps; Tply, type of plyometric; DJ, depth jump; HJ, hurdle jump; CMJ, countermovement jump; VJ, vertical jump; SLJ, standing long jump; M, mixed; R, rest (s); IR, interday rest (h); TT, *T* test, IAT, Illinois agility test; SR, shuttle run; HAR, hurdle agility run.

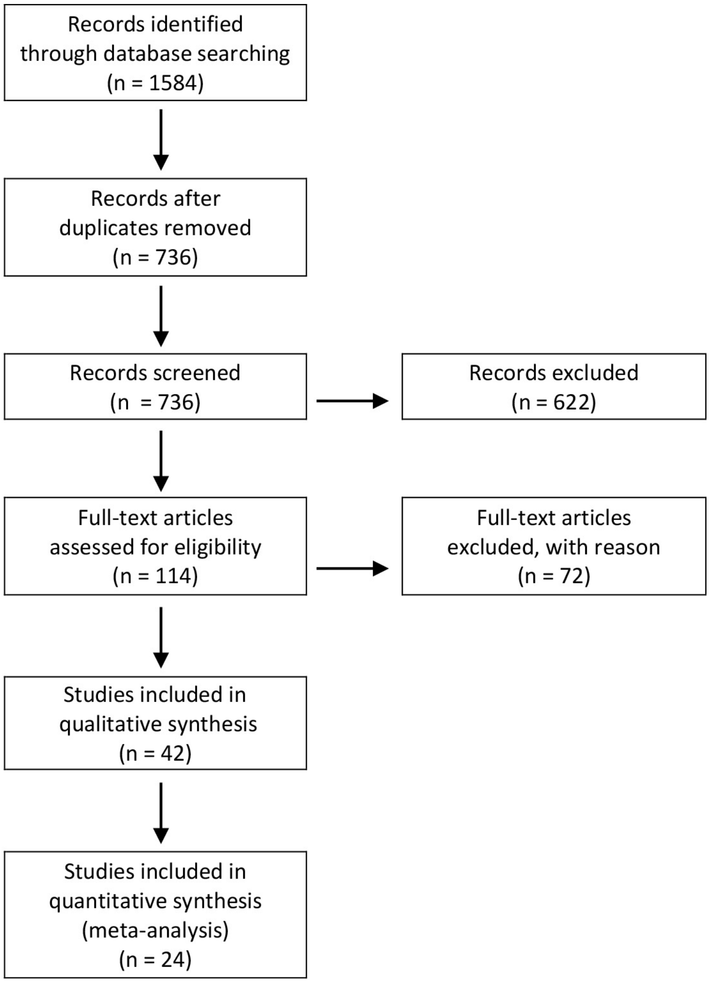

Figure 1 — Criteria for selection of articles for review.

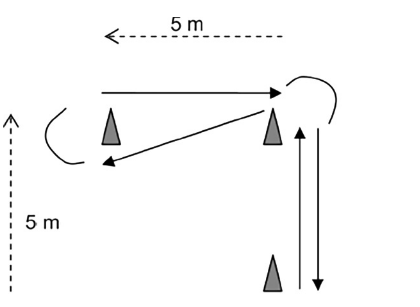

Figure 2 — L-Run. For the L-run, 3 cones were placed 5 m apart in the shape of an L. Players were instructed to run as quickly as possible along the L.

the magnitude of sample size of each study. Therefore, correction was performed using the formula $1 - 3/(4m - 9)$, where $m = n - 1$, as proposed by Hedges and Olkin.[37]

Statistical Analyses

To determine the effects of the categorical independent variables (type of population, practice of plyometrics, fitness, gender, sport activity, and program exercises [type of exercise, intensity of session, type of plyometrics, rest between sets, and training sessions]) on the COD-ability ES, an analysis of variance (ANOVA) was used.[34,35,38] In the case of quantitative independent variables (eg, age, height, duration of the treatment in weeks, number of total jumps) a Pearson (*r*) correlation test was used to examine the relationships between COD ESs and variable values.[39] The α level was set at $P \leq .05$ for statistical significance. In addition, data were assessed for clinical significance using an approach based on the magnitudes of change. Threshold values for assessing magnitudes of ES were <0.35, 0.35 to 0.80, 0.80 to 1.50, and >2.0 for trivial, small, moderate, and large, respectively[38] (Figure 3).

Results

The analysis showed that the average ES of the experimental group (0.96, n = 46, –0.68 s) was significantly higher ($P < .05$) than the ES of controls (–0.02, n = 25, 0.02 s).

With regard to subject characteristics, the results indicate a significant correlation coefficient for body mass ($r = .316$) and height ($r = .425$) with the magnitude of the ES and no significant correlation coefficient for age ($r = .260$) and group size ($r = .185$) with the magnitude of the ES (Table 2). The ANOVA showed significant effects in some of the variables measured (ie, fitness level, $P = .017$, and sport activity, $P = .027$). However, there was no significant effect ($P < .05$) in the variables of gender and practice of plyometrics.

The ANOVA showed no differences in ESs regarding the intensity of session ($P = .372$), the type of exercises ($P = .818$), the rest between training sessions ($P = .384$), and rest between sets ($P = .338$). However, significant differences were found among the types of plyometrics ($P = .002$) (Table 3).

There was no significant relationship ($P < .05$) between the frequency of sessions/wk ($r = .139$), program duration (wk) ($r = .063$), and number of total jumps ($r = .140$) with COD ES (Table 4). No differences in ES ($P = .799$) were found among the different COD tests (Table 5).

Discussion

The primary aim of this systematic review was to determine the effectiveness of PT interventions on COD performance. In addition, the secondary aim was to establish the relative importance of various subject characteristics and training variables on COD gain. Through meta-analytic procedures, the body of literature examining this form of exercise becomes much clearer, and many key points of knowledge are identified. This systematic review of 24 PT studies suggests that PT (in water or on sand, grass, or land surface) improves COD ability and that the mean effect ranges from ES = 0.26 (ie, small effect) to ES = 2.8 (ie, large effect) depending on the type of COD test measured. The findings of this systematic review (ES = 0.96; ie, plyometric group) are in line with previous studies[3–7,11,15,16–31] that used PT for COD gains and found that PT is an effective training intervention to significantly improve COD performance (>–0.68 s). These data suggest that there may be a positive transfer of the effects of PT on COD ability to athletic performance like basketball.

It has been well documented that performing PT requires sufficient muscle strength and coordination, as well as appropriate technical ability.[4,5,16,17] In the current study, 3 subgroup analyses were performed for outcomes. We found a significant difference in the effects of PT on COD ability between good versus normal or regular fitness level, which indicates that previous strength,

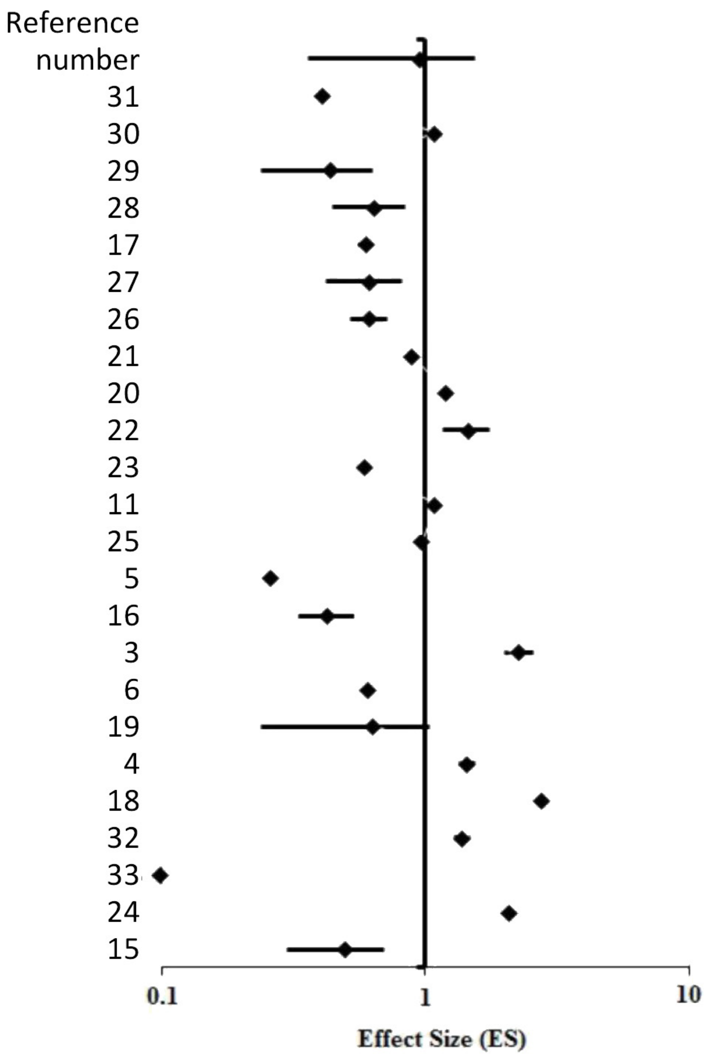

Figure 3 — Effects sizes of all studies meeting the inclusion criteria.

coordination, and neuromuscular function has positive effects on training outcome and consequently enhancement of COD ability.[3,4,22] However, the differences in COD gains were not statistically different between familiarized and not-familiarized subjects (Table 2). In this study, we found that team-sport athletes (ie, basketball players) gained greater enhancements than those in other sports. Likewise, we found positive effects of PT for COD enhancements in untrained, not-familiarized, and/or poor-fitness-level subjects. The possible mechanisms during the initial weeks in power-type strength training or PT could be neuromuscular adaptations.[3,4,39] Neural adaptations and enhancement of motor-unit recruitment are mechanisms that can lead to an improvement on the COD tests.[39] Improvements in COD require rapid force development and high power output, and it seems that PT can improve these factors.[1,15] In addition, PT may have improved the eccentric strength of the thigh muscles, a prevalent component in COD during the deceleration phase.[1] Moreover, COD tasks require a rapid switch from eccentric to concentric muscle action in the leg-extensor muscles (the SSC muscle function). Thus, it has been suggested that SSC training (PT) can decrease ground-reaction times through an increase in muscle-force output and movement efficiency, therefore positively affecting COD performance.[40]

In the current study, 3 subgroup (gender: male, female, and both) analyses were performed for outcomes. We found no significant difference in the effects of PT on COD performance between men and women. Men demonstrated gains similar to those in women (Table 2); however, this finding is probably the result of an insufficient number of studies that performed PT (42 vs 2). Based on previous studies[34,35] the percentage of improvements in performance is higher for men than for women. Previous authors indicated that men had greater SSC ability than women.[41] However, we found minimal differences between men and women in ESs (0.98 vs 0.97) and time gains (–0.67 vs –0.92 s). Very recently, in accordance with our findings, Ramírez-Campillo et al[28] examined the effects of 6 weeks of PT on COD ability (ie, IAT) in male and female soccer players and found that both the experimental groups increased their COD ability and there were no significant differences between them in COD gains (ES 0.46 vs 0.85, time gain 0.75 vs 0.4 s).

Our results suggest that higher enhancements after PT can be observed in basketball players than in other athletes such as soccer or rugby players (Table 2). It seems that PT was more specific for basketball than for other sports. Perhaps the nature of basketball (horizontal and lateral running, fast and quick movements between opponent players for crossing the ball)[4] induced greater responses to PT and consequently more COD enhancements.

In the current study, COD-ability gains were not significantly higher when plyometrics were performed on different surfaces (ie, aquatic or sand surface) and with different types of intervention (progressive PT, unilateral PT, bilateral PT, horizontal PT, vertical PT, etc). However, we should mention that when plyometrics were performed in water or on sand, higher ESs were observed (Table 3). In support of our results, previous studies reported that performing plyometrics in water environments was better than land or mat surfaces[4] and sand PT was superior to land PT[22,23] in improving COD ability. The common mechanisms for the greater enhancements in COD via PT on aquatic or sand surface could be greater neural adaptations and enhancement of motor-unit recruitment.[42,43] Performing PT on these surfaces induces more work for the muscle fibers to overcome the mobilization of resistance,[42–45] so these variables could be possible mechanisms to improve COD ability.

Intensity of exercise session plays a critical role in further adaptation. In previous studies, some authors reported that when the intensity was high during a session, there was a greater improvement in muscle performance.[19,34,35] Previous researchers found that low-intensity PT induced greater increases in COD ability than moderate-intensity PT.[16] In the current meta-analysis, COD-ability gains were not significantly higher when plyometrics were performed with high intensity, whereas we found greater, but not significant, gains for the low and moderate intensities in COD performance (Table 3).

The results of this study showed that a combination of DJs, vertical jumps, and standing long jumps demonstrated a higher ES than a single type of exercise (eg, DJs and CMJs) and/or mixed plyometric exercises (Table 3). This was mainly because of the different characteristics of movement and, thus, different use of SSC characteristics. For this reason, the combination of various exercises (DJ, vertical jump, and standing long jump) may result in greater COD gains than the other exercises. Selecting the appropriate plyometric exercise for COD improvements is very important. It has been well reported that PT is an effective training method to improve muscle performance because it enhances subjects' ability to use the elastic and neural benefits of the SSC.[34,35,39] The SSCs are affected by different types of plyometric exercises such as fast SSC jumps (ie, DJ) or concentric-only jumps (eg, SJ), or even slow

Table 2 Analysis for Independent Variables of Subject Characteristics

Independent variable	Mean (s) ± SD	*F*	*P*	Effect size	SD	n	*r*
Age (y)			.101			41	.260
Body mass (kg)			.047*			40	.316
Height (cm)			.006**			40	.425
Group size			.253			46	.185
Type of population		$F_{1,46}$ = 0.007	.932				
individual	–0.82 ± 0.58			0.95	0.55	24	
team	–0.53 ± 0.23			0.97	0.69	22	
Practice of plyometrics		$F_{1,46}$ = 0.451	.505				
familiarized	–0.80 ± 0.48			1.05	0.68	15	
not familiarized	–0.63 ± 0.45			0.92	0.58	31	
Fitness		$F_{2,46}$ = 4.505	.017*				
good	–0.83 ± 0.59			1.21*	0.69	23	
normal	–0.55 ± 0.20			0.66	0.45	16	
regular	–0.50 ± 0.27			0.84	0.24	7	
Gender		$F_{2,46}$ = 0.571	.569				
male	–0.67 ± 0.48			0.98	0.63	42	
female	–0.92 ± 0.24			0.97	0.17	2	
both	–0.60 ± 0.14			0.50	0.27	2	
Sport activity		$F_{5,46}$ = 2.849	.027*				
soccer	–0.48 ± 0.18			0.82	0.54	23	
rugby	–0.30 ± 0.00			0.61	—	1	
water polo	–0.30 ± 0.00			0.41	—	1	
basketball	–1.21 ± 0.40			1.73*	0.47	6	
physically active	–0.28 ± 0.11			1.1	1.41	2	
none	–0.92 ± 0.60			0.90	0.50	13	

$^*P < .05$. $^{**}P < .01$.

SSC jumps (ie, CMJ), and it seems that adaptations to these type of exercises are different (ES: DJ = 0.79 vs CMJ = 1.53). PT induced the rapid development of maximal force during the eccentric phase of motion.[4] It has been previously reported that PT with different exercises can influence the rate of adaptation and consequently greater improvements in COD performance,[3,4,11,19] which is in agreement with our findings.

The results of the current study indicate that there are no significant differences in rest interval between sets and magnitude of changes in COD performance. However, the rate of changes and improvements were higher for the 120-second (ES = 1.26) rest between sets in improvement of COD ability. Ramírez-Campillo et al[25] examined the effects of 6 weeks of PT using 30, 60, or 120 seconds of rest between sets on COD ability (ie, L-run) in young soccer players and found that all experimental groups improved COD ability (moderate ES) and the rate of enhancement was greater for 120-second rests between sets (ES = 1.04). The possible greater enhancement, although not significant, in COD via applying 120-second rest intervals between sets may have been due to several possible mechanisms such as better phosphocreatine resynthesis, clearance of by-products (eg, lactate, H+ ions), regulation of acid–base balance, and reconstitution of maximal power output, and these mechanisms may allow better recovery from PT and consequently gains in COD performance.[46,47]

In the recent study by Ramírez-Campillo et al,[17] the effects of interday rest on COD (ie, 10 × 5) ability after 6 weeks of PT were determined. Those authors reported no significant differences between 24 and 48 hours rest on COD performance, but the ES of 24-hour rest was minimally greater than 48-hour rest (0.63 vs 0.57). The results of the current meta-analysis showed that 72 hours of rest between training sessions was better than other times such as 48 and 24 hours (Table 3). It seems that 72 hours rest between PT sessions was appropriate to allow for adequate recovery, suggesting that these time frames of rest would be necessary to induce adequate training stimulation. The possible mechanisms could be because gains in COD with 72-hour rest intervals between training sessions include more changes in the contractile apparatus of the muscle fibers; better neural adaptations such as leg-muscle-activation strategies, intermuscular coordination, and stretch-reflex excitability; greater changes in muscle architecture (ie, a decrease in fascicle angle and an increase in fascicle length of knee extensors); and better changes in stiffness of various elastic components of the muscle–tendon complex.[48,49]

The limitation of this review was the number of articles that met the inclusion criteria. Although all articles included provide evidence that PT may improve COD performance, further research is necessary to elucidate the most effective PT for COD ability.

Typically, designing an optimal PT program is related to training load (volume and intensity) and frequency of training. In this

Table 3 Analysis of Variance Results on the Differences in Effect Size (ES) Between Various Elements of Plyometric-Training-Independent Variables of Program Elements

Independent variable	Mean (s) ± SD	*F*	*P*	Effect size	SD	n
Type of plyometric exercise		$F_{12,46} = 0.610$	.818			
aquatic	–1.49 ± 0.56			1.40	0.14	2
land	–0.51 ± 0.28			1.04	0.72	23
mat	–0.79 ± 0.49			0.97	0.61	4
grass	–0.55 ± 0.19			0.66	0.37	4
sand	–1.45 ± 0.61			1.30	0.46	5
bilateral	–0.30 ± 0.00			0.42	—	1
unilateral	–0.50 ± 0.00			0.80	—	1
bilateral + unilateral	–0.50 ± 0.00			0.66	—	1
progressive	–0.85 ± 0.00			0.82	—	1
not progressive	–0.70 ± 0.00			0.43	—	1
vertical	–0.40 ± 0.00			0.43	—	1
horizontal	–0.32 ± 0.00			0.21	—	1
vertical + horizontal	–0.55 ± 0.00			0.70	—	1
Intensity of session		$F_{4,46} = 1.095$	.372			
low	–0.37 ± 0.15			1.24	1.09	4
low to moderate	–0.13 ± 0.00			0.89	—	1
moderate	–0.82 ± 0.51			1.04	0.60	30
moderate to high	–0.73 ± 0.02			0.60	0.04	2
high	–0.41 ± 0.19			0.65	0.36	9
Plyometric exercises		$F_{3,46} = 5.846$	.002**			
depth jump	–0.64 ± 0.45			0.79	0.39	14
countermovement jump	–1.40 ± 0.74			1.53	0.35	3
depth jump, vertical jump, standing long jump	–0.93 ± 0.41			2.30*	0.33	2
hurdle jump, depth jump	–0.20 ± 0.00			0.10	—	1
mixed	–0.62 ± 0.40			0.92	0.59	26
Rest between sets		$F_{4,34} = 1.186$	.338			
30 s	–0.30 ± 0.00			0.82	0.29	2
60 s	–0.75 ± 0.48			0.86	0.44	15
90 s	–0.42 ± 0.18			0.87	1.08	5
120 s	–1.08 ± 0.55			1.26	0.67	11
180 s	–0.20 ± 0.00			0.10	—	1
Rest between sessions		$F_{2,40} = 0.983$	.384			
24 h	–0.47 ± 0.26			0.65	0.60	3
48 h	–0.61 ± 0.39			0.86	0.60	24
72 h	–0.91 ± 0.62			1.08	0.50	13

$^*P < .05$. $^{**}P < .01$.

Table 4 Pearson Correlation Coefficients (*r*) Between Various Program Elements and Training Gains

Training-program variable	ES	SD	n	*P*	*r*
Sessions/wk	0.96	0.61	46	.139	.358
Program duration (wk)	0.96	0.61	46	.063	.677
Number of total jumps	0.95	0.58	36	.140	.414

Abbreviation: ES, effect size.

study we did not find significant correlations between frequency, number of jumps, and program duration and COD gains (Table 4), and we cannot strongly recommend optimal training variables to improve COD ability. Since there were no statistically significant findings for these variables, it is suggested to give a range for each of these variables that the majority of studies with gains from PT found. From Table 1 it can be seen that the recommendations could be made that gains were made most often when the frequency was 2 to 3 d/wk for 6 to 8 weeks; the total of jumps in this time span was

Table 5 Analysis for Independent Variables of Outcome Measurement

Independent variable	Mean (s) ± SD	ES	SD	n	$F_{7,46}$	P
Agility test					0.540	.799
T test	–0.89 ± 0.49	0.87	0.40	13		
Illinois agility test	–0.84 ± 0.61	0.99	0.71	13		
Shuttle run	–0.44 ± 0.19	1.36	0.93	4		
505	–0.55 ± 0.07	1.40	0.14	2		
Agility 10-m	–0.42 ± 0.09	0.89	0.81	8		
10 × 5 agility	–0.73 ± 0.21	0.60	0.04	2		
Hurdle agility run	–0.13 ± 0.00	0.89	—	1		
L-run	–0.36 ± 0.05	0.98	0.09	3		

800 to 1200 jumps at a moderate to high intensity. The rest between sets was found to be 60 to 120 seconds, and rest between sessions, 48 to 72 hours, for positive gains. Therefore, this recommendation is based on the range of each variable that has been found to be effective for gains in COD ability.

Practical Applications

PT can be recommended as an effective form of physical conditioning for enhancing the COD ability, yet the effects of PT could vary because of a large number of variables such us program duration, training volume, rest interval, intensity, and subject characteristics (gender, age). These variables should be taken into account by strength and conditioning professionals to design an optimal PT program to enhance COD ability for a given sport. Therefore, in addition to the well-known training methods such as strength and power training in the weight room, strength and conditioning professionals may well incorporate PT into an overall conditioning program for athletes to achieve a high level of COD performance.

Conclusion

In conclusion, the current meta-analysis demonstrates that PT significantly improves COD performance. The estimated improvements in COD as a result of PT could be considered practically relevant—for example, an improvement in COD time of >–0.68 seconds (ie, ES = 0.96) could be of high importance for athletes in sports relying on COD ability. According to our meta-analysis results, when subjects can perform plyometric exercises with adequate technique and have good fitness level, the training gains are better, although the rate of COD gain is similar in men and women after PT. In relation to the variables of PT design, it appears that 7 weeks (with 2 sessions/wk) using moderate intensity and 100 jumps per training session with 72-hour rest intervals tends to achieve improvements in COD ability. Another important conclusion is that there is minimal profit from performing PT in water or on sand and that it is more beneficial to combine plyometrics (DJs + vertical jumps + standing long jumps) than to use only a single modality.

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